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Technical Note 6-88

MILITARY SYMBOLOGIES: AN OVERVIEW AND SELECT ANNOTATED BIBLIOGRAPHY

Daniel J. Pond

August 1988
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U. S. ARMY HUMAN ENGINEERING LABORATORY

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This report discusses critical symbology issues and areas of symbology research considered to merit additional inquiry. Variables that could impact symbol effectiveness are categorized and discussed as personnel (e.g., soldier experience), operational (e.g., combat stress), and technological (e.g., display type) influences.

Three themes emerged from this review. First, across all agencies, operations, and systems, there is a recognized need for improved symbologies in order to maintain or enhance efficiency under increasingly difficult operational conditions. Second, there is a general, if ill-defined, call for some degree of symbology standardization. Third, one or more aspects of a traditional "systems approach" to design are frequently considered crucial elements of the operational system for which a symbol set is being developed.

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19. Finally, two actions appear essential in charting an efficient and meaningful course for symbology research. First, an assessment must be made of the current status of all symbology research programs regarding mission, approaches, problems, and plans. Second, a mechanism must be created to assure the continued exchange of up-to-date information among members of the symbology research community.

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MILITARY SYMBOLOGIES: AN OVERVIEW AND SELECT ANNOTATED BIBLIOGRAPHY

Daniel J. Pond
Florida Institute of Technology

August 1988

APPROVED: John D. Weisz
JOHN D. WEISZ
Director
Human Engineering Laboratory

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U.S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005-5001

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CONTENTS

EXECUTIVE SUMMARY

This report is a brief, initial fact-finding effort on the part of the Aviation and Air Defense Division of the U.S. Army Human Engineering Laboratory (HEL) to assess the current status of military symbology research. This report provides an explanation of the critical symbology issues, details those areas of symbology research considered to merit additional inquiry, and includes an annotated bibliography of some key studies and reports relating to these topics.

Three themes emerged from the present effort. First, across all agencies, operations, and systems, there is a recognized need for improved symbologies in order to maintain or enhance efficiency under increasingly difficult operational conditions. Second, there is a general, if ill-defined, calling for some degree of symbology standardization. Third, one or more aspects of a traditional "systems approach" to design are frequently considered crucial elements of the operational system for which a symbol set is being developed.

Previously adequate symbol sets have been taxed by (a) the expanded range of the modern battlefield, (b) the numbers and variety of military equipment now needing to be represented, and (c) the rate at which situational information must be updated. For these reasons, as well as to assure compatibility with the array of electronic displays used in modern Army systems, the need for new symbologies is widely recognized.

The population of U.S. soldiers varies widely with respect to such characteristics as native language, culture, educational level, and length of military service. While symbols may have different meanings for individuals with different backgrounds, little or no research has investigated the impact of individual differences on symbology effectiveness. Although such effectiveness has typically been assessed by the speed and accuracy of symbol perception and interpretation, future research must consider a commander's workload and focus on the higher-level cognitive processes required for battlefield decision making under combat stress.

Developers have modified or created symbologies that take into account the different requirements imposed by a hard-copy printout versus a cathode-ray tube (CRT) display; but, in spite of the myriad of new electronic displays, little such effort by symbology researchers is evident. A critical issue is whether to develop a unique symbol set for each new display or operational system, as is presently done, or to establish a single or limited number of standardized symbologies for use throughout the Department of Defense (DoD). Soldiers are likely to be called upon to operate a number of different systems during the course of their military careers, and military operations frequently require communications between operators of different systems. Symbology standardization would enhance the "behavioral interoperability" of systems, thereby improving military effectiveness.

Two actions appear essential in charting an efficient and meaningful course for symbology research. First, an assessment must be made of the current status of all symbology research programs with regard to mission, approaches, problems, and plans. Second, a mechanism must be created to assure the continued exchange of up-to-date information among members of the symbology research community. The criticality of joint interservice and international military operations requires that these two activities be considered, at least throughout the U.S. Department of Defense. It is recommended that this first task take the form of a survey similar to the one performed by the U.S. Army Research Institute in 1978 (Sidorsky, Gellman, & Moses, 1979) and that the second function be accomplished by creating a Symbology Working Group as part of the Controls and Displays Group within the DoD Human Factors Engineering Technical Group.

A number of variables that could impact symbol effectiveness appear to merit further research. These are categorized as personnel (e.g., soldier experience), operational (e.g., combat stress), and technological (e.g., display type) influences and are discussed in this report.

MILITARY SYMBOLOGIES: AN OVERVIEW AND SELECT ANNOTATED BIBLIOGRAPHY

INTRODUCTION

In the summer of 1987, the Aviation and Air Defense Division (AADD) of the U.S. Army Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Maryland, undertook a short-term project to survey the recent research on military symbology. This was a time-defined rather than a goal-defined project that represented an initial fact-finding activity on the part of HEL. The present report, which details the findings of these efforts, provides an explanation of the critical symbology issues, details those areas of symbology research considered to merit additional inquiry, and includes an annotated bibliography of some key studies and reports related to these topics. Because of the time limit set for this project, the literature review was conducted to locate studies representative of the breadth of symbology research rather than to compile all relevant sources.

Human use of symbols has been said to have played a prominent role in the development of society and human culture (Gamezo, Lomov, & Rubakhin, 1977). In addition to such common iconic representations as the knife and fork silhouette on a roadside sign indicating an upcoming restaurant, symbols can also take the form of semaphore signals, morse code, braille, and standard alphanumeric text.

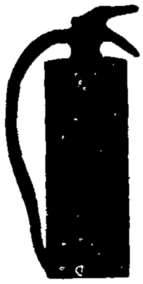
Symbology systems for representing battlefield status have been traced back hundreds of years to the time of Napoleon (Ciccone, Samet, & Channon, 1979; Florence & Geiselman, 1986). Because past battlefields were often limited both in size and rate of change, effective situational representations were easily achieved with relatively few symbols on a tabletop situation display. Such previously adequate symbol sets have been severely taxed by the greatly expanded range of the modern battlefield, by the numbers and variety of military equipment now needing to be represented, and by the rate at which situational information must be updated.

SYMBOLOGY OVERVIEW

Coding Techniques

Three categories of visually presented, shape-coded symbols are used: pictorial, abstract, and arbitrary (Collins, 1982; see Yoeli & Loon, 1972 for an alternate taxonomy). Common examples of each category are displayed in Figure 1. Pictorial symbols are also known as pictographic, iconic, or figural representations. Whether presented in outline or silhouette form, these symbols physically resemble the object they represent and are said to possess "iconicity" (Sam[illegible] , Geiselman, & Landee, 1980). Abstract or concept-related symbols refer to perceptual

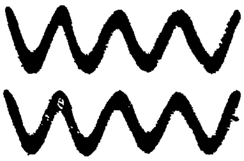
Pictorial (also known as pictographic, figural, iconic)



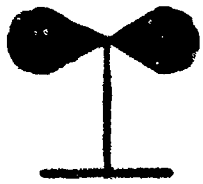
fire extinguisher[a]

helicopter[b]

Abstract (also known as concept-related)



water[a]



helicopter[b]

Arbitrary

biological hazard[a]

helicopter[b]

Figure 1. Categories of symbols.

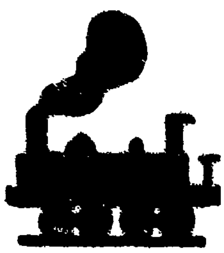
[a]From The Development and Evaluation of Effective Symbol Signs by B. L. Collins, 1982, p. 4.
[b]From Symbology Sourcebook for Military Applications by B. G. Knapp, 1986, pp. 35, 36.

concepts rather than the actual objects and, as implied by the name, arbitrary symbols have no inherent association with the represented object or concept.

The knife and fork symbol may be used as an abstract representation of a restaurant, but could in other circumstances, be used as a pictographic symbol for a store's silverware department. The depiction of such entities as "water," "maintenance," "unit strength," and "ambush," requires the use of conceptual or arbitrary symbols.

No single approach to symbol design is best for all circumstances, however. Pictographic representations are said to possess greater "imageability" and stronger stereotypical association because of their true depiction of the object (see Samet et al., 1980). Continuing controversy exists, however, regarding the extent to which these features result in faster and/or longer lasting learning of the symbol-object association (cf. Earl, 1982; Florence & Geiselman, 198? Knapp, 1986).

Further, Bersh, Moses, and Maisano (1978) point out that pictographic representations may become obsolete as advanced technologies alter the silhouette of the object depicted (see Figure 2).



steam engine

gasoline pump

Figure 2. Obsolete pictographs.

Adapted from The Development and Evaluation of Effective Symbol Signs by B. L. Collins, 1982, p. 18.

On the other hand, although abstract representations have sometimes been found to be "equally meaningful" to their pictographic counterparts (Knapp, 1986), individual differences in the mental imagery associated with a symbol may cause them to be misinterpreted. For example, Figure 3 depicts the symbols used to represent "gun/antitank/light" and "missile/antitank/light" by the Tactical Operations System. As also shown in Figure 3, Hawrylak and Miller (1985, p. 35) have chosen their "mechanized infantry" symbol "because of its similarity to a mechanized vehicle." Similarly, Kopala, Reising, Calhoun, and Herron (1982) have noted individual differences in the expected association of the symbol "A" with aircraft versus antiaircraft artillery.

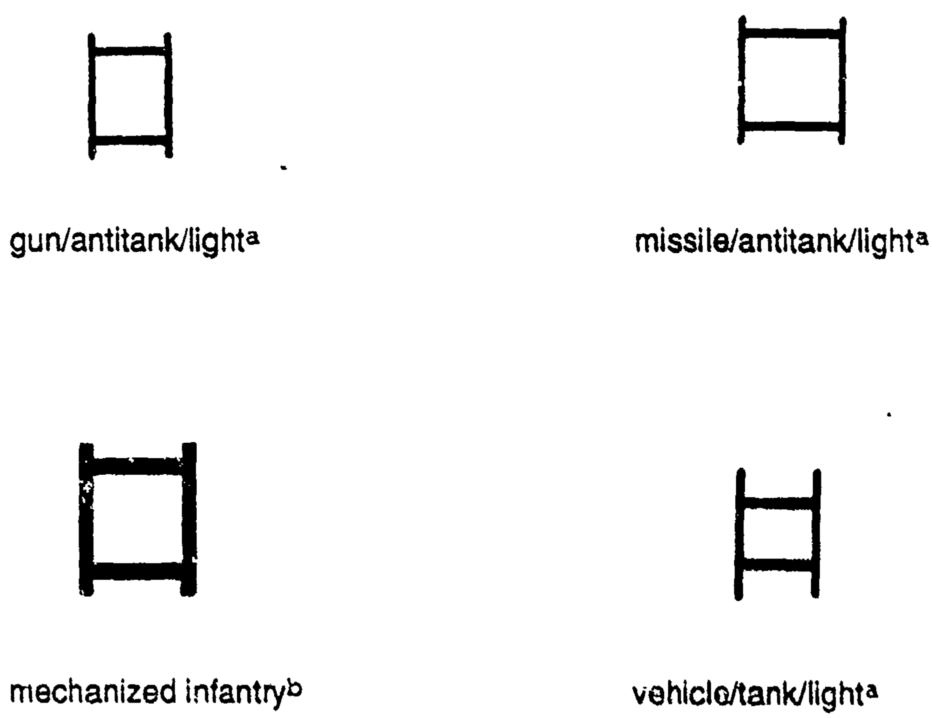


Figure 3. Differences in abstract symbol usage.

[a]From Symbology Sourcebook for Military Applications by B. G. Knapp, 1986, pp. 68, 75, 80.
[b]From Enhanced Tactical Symbology for Command and Control of Ground Forces by M. N. Hawrylak and J. W. Miller, 1985, p. 35.

Although the focus of the present discussion is on various shape-coding techniques, visually presented information may be coded in other dimensions such as color, size, inclination, brightness, flash rate, etc. For the interested reader, McCallum and Rogers (1982) provide an excellent review of such coding techniques and offer examples of the ways these dimensions may be used in systems with different degrees of redundant coding.

Prescription for an Ideal Symbology

Sidorsky, Gellman, and Moses (1979) have set forth the following four criteria for effective symbologies:

1. compatibility with user needs
2. compatibility with user abilities
3. compatibility with user tasks
4. compatibility with display capabilities

These criteria are easily recognized as components of a systems approach to design. Examples of problems encountered with symbol systems that have been developed without sufficient concern for each of these areas and have failed to achieve the requisite degree of "compatibility" follow.

User ability issues are discussed in the Personnel Influences section, user needs and user tasks are considered together in the Operational Influences section, and display capabilities are discussed in the section on Technological Influences.

Personnel Influences

Hemingway, Kubala, and Chastain (1979, p. 2-10) report that "symbols may have different meanings for different observers, depending upon their background, experience, and training" (see Figure 3). Problems undoubtedly increase in severity and frequency as less homogeneous personnel and/or hardware populations are considered. For example, Simpson (1980, p. 47) has detailed U.S. Army and Republic of Korea Army interoperability problems derived from differences in map symbologies, and he has concluded that

> it is the small differences which can lead an officer of either Army to believe that he understands an operations overlay when he truly does not. Improper communications can waste lives.

Similarly, in surveying the U.S. Army's symbology research and development efforts, Sidorsky et al. (1979, p. 12) acknowledge the need to make symbologies "compatible, adaptable, and acceptable to the NATO environment."

It is not necessary to adopt a world-wide perspective to find such problems, however. Significant interindividual differences in variables such as native language, culture, length of military service, and educational level are readily found within the population of U.S. soldiers. Further, one might reasonably anticipate that intraindividual variations in experience, workload, response to combat, shift work, and/or environmental stressors could impact the effectiveness of a symbol set.

A survey of aircraft display symbology was conducted by Pearson, Rundle, and Hoffman (1978). As displayed in Table 1, they compared preferences for pictorial, alphanumeric, abstract simple lines and curves, and abstract geometric shapes such as circles to represent various tactical events and objects. Respondents were either college engineering students, F-111 pilots, or F-15 pilots. Table 1 also lists the symbol types previously chosen by a Symbology Standardization Committee (SSC), which included U.S. Air Force human factors personnel.

Although there is some consensus on pictorial representations of elements such as ships and ground troops, a general lack of agreement among these four sets of preferences may be seen in Table 1. Interestingly, however, Pearson et al. (1979) note the closest agreement in preferences was recorded between the SSC and the students, perhaps demonstrating the importance of an experience--or lack of experience--factor in symbol set design.

As Cahill (1976, p. 653) has indicated, "the symbol designer...must know very well the experiential and informational background of the narrowly defined population of users for whom he is designing."

Operational Influences

Landee, Geiselman, and Clark (1981, p. 56) report that an evaluation of the Army's conventional symbology (FM 21-30 [Department of the Army, 1970]--since superseded by FM 101-5-1 [Department of the Army, 1985]) held that this symbol set was "designed for an era of more time and less information." Advances in modern C^3I (command, control, communication, and intelligence) technologies will make still more information available and at faster rates. Increasingly, a commander's ability to make quick, correct battlefield decisions will depend upon his ability to accurately perceive and process all of the available data. This increase in data transmission can increase the cognitive as well as the perceptual demands on the commander during critical situations (see e.g., Channon, 1976; Geiselman, Landee-Thompson, & Samet, 1986), and can, in turn, induce erroneous and possibly catastrophic command decisions.

Current military symbology has frequently been found to be lacking much information required for battlefield decision making (see e.g., Ciccone et al., 1979; Hawrylak & Miller, 1985; Hemingway et al., 1979; Landee, Samet, & Gellman, 1980; and Sidorsky et al., 1979). By performing a cluster analysis on responses from Army officers to 272 tactical questions, Landee et al. (1980) were able to distinguish seven

Table 1

Summary of Preferred Coding Methods for Designing Tactical Symbology

	Symbol class			
Object/Event etc.	SSC[a]	Students	F-15 pilots	F-111 pilots
Target	pictorial	pictorial	geometric	geometric
Initial point	–[b]	alphabetic	geometric	geometric
Ships	pictorial	pictorial	pictorial	pictorial
Radar installation	pictorial	pictorial	pictorial	pictorial
Waypoint	lines, etc.	alphabetic	geometric	geometric
Aircraft	lines, etc.	lines, etc.	geometric	pictorial
Nuclear blast	pictorial	pictorial	pictorial	pictorial
Tanks	–[b]	pictorial	pictorial	pictorial
AAA[c]	alphabetic	geometric	pictorial	pictorial
Emergency base	geometric	alphabetic	alphabetic	geometric
Downed aircrew	lines, etc. (orientation)	lines, etc. (orientation)	pictorial	pictorial
Ground troops	pictorial	pictorial	pictorial	pictorial
Safe area	lines, etc.	geometric	alphabetic	alphabetic
Base of origin	geometric	geometric	alphabetic	geometric
SAM[d] site	–[b]	alphabetic	pictorial	pictorial
Origin (friendly, enemy, unknown)	geometric	alphabetic	geometric	alphabetic
Hand-held SAMs	alphabetic	lines, etc.	alpha-num	lines, etc.
Bombing Area	lines, etc.	lines, etc.	alphabetic	geometric
Convoy	pictorial	lines, etc.	pictorial	pictorial

[a]SSC - Symbology Standardization Committee
[b]Data was not listed in the original table
[c]AAA - artillery and antiaircraft
[d]SAM - surface-to-air missile

Note. Adapted from Studies in Tactical Symbology: I. Preferred Tactical Symbology for Joint Tactical Information Distribution System (JTIDS) (p. 10) by W. H. Pearson, M. F. Rundle, and M. S. Hoffman, 1978, Wright Patterson AFB, OH: Aerospace Medical Research Laboratory.

major categories of battlefield information requirements. The category names, which describe the central theme of each cluster's information, are

- friendly
- enemy
- time/capability
- status
- activities/procedures
- terrain/routes
- planning

Results indicate that nearly half of all required information was not made available through conventional symbology, and that as little as 6 percent of the needed "friendly" data were made obvious by the display.

To increase symbol content, however, risks overloading a commander's higher-level cognitive processes during critical operations. The preferred symbol set, then, might differ under low- and high-workload operations, and Geiselman et al. (1986, p. 901) have described a "selective callup system" that enables commanders to display only the necessary level of symbol detail. A commander must choose the appropriate data on which to base his decision, however. This may or may not involve the same skills and abilities as those required for selecting relevant data from among much irrelevant data and may, in fact, increase the commander's workload by creating another level of decision making: What could be displayed? What should be displayed? When should it be displayed? In addition to the performance measures now used (i.e., speed, error), it may be of value to incorporate into symbology development programs other workload assessment techniques including physiological (e.g., evoked cortical potentials), and/or subjective measures (e.g., the Subjective Workload Assessment Technique).

Samet et al. (1980) constructed a taxonomy of behavioral symbol-use processes (Table 2). These are a multilevel set of interdependent processes in which higher-level operations are composed of a combination of lower-level operations. For example, counting is said to involve detection, identification, and search.

Symbology research has often used tasks requiring perceptual learning, association, detection, identification, search, and comparison. While speed and accuracy of symbol interpretation have been considered to be the most important criteria in assessing symbol effectiveness (Davis, 1969; Earl, 1982), Hemingway et al. (1979, p. 1-3) have acknowledged that

> the human operator acts upon his interpretation of the entire display. He must not only be able to accurately and rapidly perceive individual symbols, he must also make decisions and take actions on the basis of the total information presented.

Table 2

Taxonomy of Symbol-Use Processes

Symbology Acquisition	
Perceptual Learning	acquisition of a code necessary for future recognition of a form
Association	acquisition of a mental link between a form and the concept that it portrays
Processing Individual Symbols	
Detection	acknowledgment of the presence of a form
Identification	interpretation of a detected form
Search	determination of the location of an identified form
Tracking	sustained detection of a mobile form
Updating	acknowledgment of an alteration of a form
Processing Multiple Symbols	
Comparison	acknowledgment of sameness and/or differences among two or more identified groups
Counting	keeping track of the number of instances that a given form is encountered
Pattern Recognition	interpretation of the spatial arrangement of two or more identified forms
Integration	combination of information from two or more identified forms toward a simplified characterization of the set of forms

Note. Adapted from An Experimental Evaluation of Tactical Symbol-Design Features (p. 3) by M. G. Samet, R. E. Geiselman, and B. M. Landee, 1980, Alexandria, VA: U. S. Army Research Institute for the Behavioral and Social Sciences.

Thus, a commander's ability to effectively assess battlefield status depends heavily on the less frequently studied higher-level processes of tracking, updating, counting, pattern recognition, and integration (e.g., see Earl, 1982).

Technological Influences

Symbol set research and development has typically used paper, transparent overlay, photographic slide projection, and/or cathode-ray tube (CRT) presentations of experimental stimuli (cf. Bowen, Andreassi, Traux, & Orlansky, 1959; Florence & Geiselman, 1986; Geiselman, Landee, & Christen, 1982; Howell & Fuchs, 1961; McCann, 1979). Display technologies have proliferated, however, and Chan, Swanson, and Whisnant (1980) detail dozens of display devices available for presenting operations and intelligence information. These devices include plasma, light-emitting diode, liquid crystal, electroluminescence, laser, and various three-dimensional techniques. The problem, of course, is the extent to which a symbol that is developed and refined using display technique X is suitable when displayed using technique Y.

Consider, for example, the propeller-shaped abstract helicopter symbol shown in Figure 1. In attempting to present a similar icon on an 8 x 8-inch (240 x 240-pixel) CRT, Jarosz and Rogers (1982, p. 7) found the resulting symbol to be "not particularly effective" even though it occupied 70 times the area required for effective reproduction of the printed version (see Figure 4).

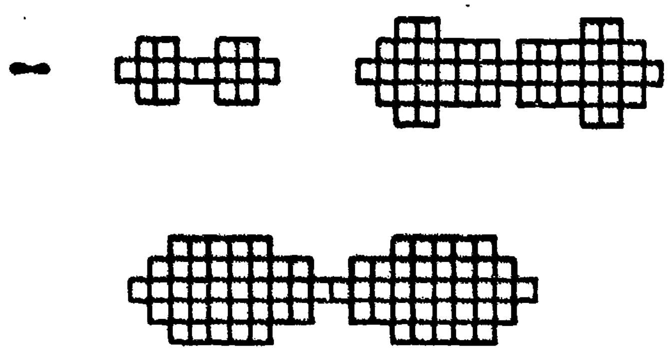


Figure 4. Symbol-display incompatibility.

From <u>Evaluation of Map Symbols for a Computer-Generated Topographic Display: Transfer of Training, Symbol Confusion, and Associated Value Studies</u> by C. J. Jarosz and S. P. Rogers, 1982, p. 7.

Abramson and Snyder (1984) have noted that the legibility of electronic displays is affected by variables quite different from those of printed text. One such variable is the possibility of local failures (i.e., in only portions of the display) with many electronic display types. For example, Abramson and Snyder (1984, p. 3) state that

AC [alternating current] plasma displays tend to fail by having discrete cells remain 'off' regardless of their intended state. Similarly, thin-film transistor addressed electroluminescent displays can fail in a single cell or pixel mode and also in a complete line, either vertical or horizontal. Matrix addressed displays tend to fail a line at a time, either vertical or horizontal, depending on the failed driver location and display orientation.

Research to date regarding such display differences appears to have focused on the legibility of alphanumeric characters as depicted through different font configurations. Clearly, consideration of such issues must become an essential component of symbology development as well. It is also essential that a symbol set be designed to be suitable for effective presentation on the least capable or least user-compatible display in the system under both normal and degraded modes of operation.

Davis (1971) compared the paper and the CRT presentation of radar symbologies and found that the CRT tube curvature and phosphor characteristics could adversely affect individual symbol effectiveness through size distortions and reduced contour sharpness (see also, Sarli & Carter, 1982). Kopala et al. (1982) have recognized the need to create a symbol set that is suitable for use both with the raster-written CRTs on F-16 and A-10 aircraft, as well as with the combination stroke- and raster-written CRTs used for F-14 and F-15 displays. The technical problem here is the inability of raster-written displays to reproduce oblique lines smoothly (Pearson & Shew, 1980).

Given the current widespread use of high-resolution color CRTs in systems development and research organizations, a similar loss of symbol effectiveness might be anticipated as a user attempts to use a CRT-created symbol under the degraded conditions afforded by a 17 x 35-inch LED display (see e.g., Hawkins, Reising, & Woodson, 1984). Consider, for example, the difficulty in discriminating among the physically similar symbols depicted in Figure 3 if they are presented under any number of less-than-ideal circumstances such as on a low-resolution display, in glare, or during combat.

The situation is further complicated by the advent of integrated electronic displays that can present data from a number of different sources or systems onto a single display. The importance of compatible symbologies in these circumstances has been noted for aircraft (Herron, 1980) and radar displays (Gombash et al., 1982).

Research Emphases

A good deal of research has focused on the perceptual aspects of symbolic representations, that is, the speed at which someone can identify a particular symbol or type of symbol, and/or the extent that one symbol is readily discernible from another (see e.g., Davis, 1971; Jarosz & Rogers, 1982). A number of studies have examined the impact on

symbol discriminability of such figural characteristics as number of lines and arcs, symmetry, continuity of symbol lines, and "figural goodness" (see Hemingway et al., 1979 and Honigfeld, 1964 for reviews). While noting that symbology developers frequently cite studies of visibility of geometric forms and other Gestalt-related phenomena as rationale for symbol selection, Davis (1969, p. 4) has concluded that such data "...have little to offer in the search for the most desirable symbol."

While assurance of discriminability has been characterized as "a necessary first step" in symbol system development (Williams & Teichner, 1979, p. 5), and while it is the "logical precursor" (Geiselman, Landee, & Christen, 1985, p. 1) of higher-level processes, the effective operation of modern military systems requires that symbology research no longer give "primary emphasis" (Geiselman et al., 1985, p. 2) to such basic issues unless they are studied entirely within the context of an operational system. Indeed, Remington and Williams (1986, p. 407) recommend that a search for symbology display principles be "...restricted to a class of displays that will be used under similar circumstances."

Surprisingly often, however, researchers appear to have ignored this approach and have developed symbologies with little regard for the context in which the symbols were to be used. In a military context, for example, Earl (1982) has reported that he was able to locate only five studies that used conventional military symbology as stimulus material for interpretation tasks.

Information Requirements

Based on the present review, it appears that the operational (user needs/user tasks) issues have received the most research attention, and that within this domain, considerable attention has been focused on battlefield information requirements. As previously indicated, the Army's conventional symbology has repeatedly been found lacking in its ability to depict certain types of critical information. The response to these deficiencies has taken two tracks: on-site "personalization" of conventional symbologies and the development of new symbol sets.

Personalization techniques such as operator-added alphanumerics and symbol-shape alteration have proliferated and, in fact, have even been used when the same information is already made obvious by the display (see e.g., Landee et al., 1981). The problem here, of course, is the resulting lack of standardization across systems, shifts, or even operators, and this "...is likely to reduce the communication value of the display and may result in misunderstandings, confusion, errors, or time delays" (Landee et al., 1981, p. 2).

There has also been a proliferation of new symbol sets or sets that attempt to supplement conventional symbology in order to represent additional data such as combat effectiveness or unit threat value (see

Knapp, 1986 and Samet et al., 1980 for discussions). For example, Figure 5 shows the "enhanced" version of Hawrylak and Miller's (1985) mechanized-infantry symbol (see Figure 3) and lists the added information types presented.

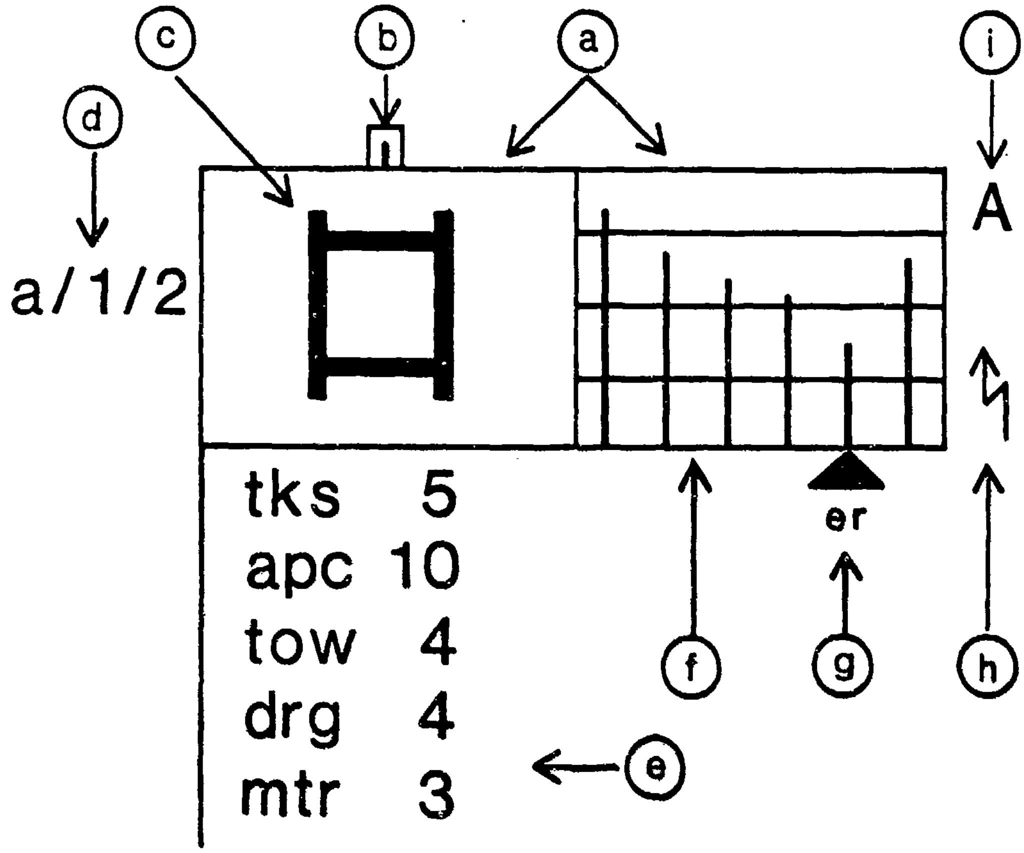
Knapp's (1986) comprehensive hard-copy listing of available military symbols depicts over 1,000 symbols from dozens of symbol sets, including those developed for air defense, radar, tactical, and other military systems. This Symbology Sourcebook for Military Applications (Knapp, 1986) contains many cases in which two or more different symbols are used to portray the same concept. For example, the helicopter representations shown in Figure 1 are only 3 of the 30 such figures presented by Knapp. Additionally, there are a number of instances in which the same symbol has been used to depict different objects or events. Again, the lack of standardization may degrade the overall quality of communication (Knapp, 1986).

Consider, for example, the series of symbols depicted in Figure 6. An individual familiar with the symbol set from which symbol A is taken (FM 21-30 [Department of the Army, 1970]) might mistakenly interpret symbol C (a sighted enemy helicopter) as having been destroyed--clearly, an error with potentially disastrous consequences. Further, in depicting the complex modern battlefield on small-screen electronic displays, superimposition of one symbol on another can be expected to occur. In addition to the display clutter and symbol-masking that is created (see e.g., Hemingway et al., 1979; McLaughlin & Barclay, 1987), the inadvertent superimposition of symbol B over any other symbol would yield an incorrect representation of friendly and/or enemy status.

Similarly, although symbol D is the widely used representation for infantry, in certain symbol configurations it could be misidentified as a destroyed pillbox (symbol E) or command post (symbol F). The ability to distinguish between symbols E and F depends not only on a commander's perceptual abilities, but also on the ability of the display hardware to make evident the minimal distinctions between these symbols.

Symbology Standardization

Applied human factors investigations of military systems symbology date at least as far back as the 1940s (e.g., Bartlett & Williams, 1947), although many examples of earlier basic form perception research may be found (e.g., Kleitman & Blier, 1928). As evidenced in research over the past four decades, the need for symbol standardization is an issue of continuing concern (see e.g., Bowen et al., 1959; Carter, 1981b; Davis, 1971; Honigfeld, 1964). Twenty years after Honigfeld (1964, p. 1) noted that "since symbols have not been specified formally, the result is a unique code for each system," Landee and Geiselman (1984, p. 3) still found that "...in the absence of standards, system-by-system development is a likely consequence."



(a) unit location (stem in lower left corner points to command post)
(b) unit size
(c) unit type
(d) unit identification
(e) major weapons and equipment
(f) unit status (from left to right: personnel, ammunition, weapons, POL, equipment, combat effectiveness)
(g) emergency resupply (flashing symbol)
(h) communication status
(i) mission

Figure 5. Enhanced tactical symbology for friendly units.

Adapted from Enhanced Tactical Symbology for Command and Control of Ground Forces by M. N. Hawrylak and J. W. Miller, 1985, p. 33.

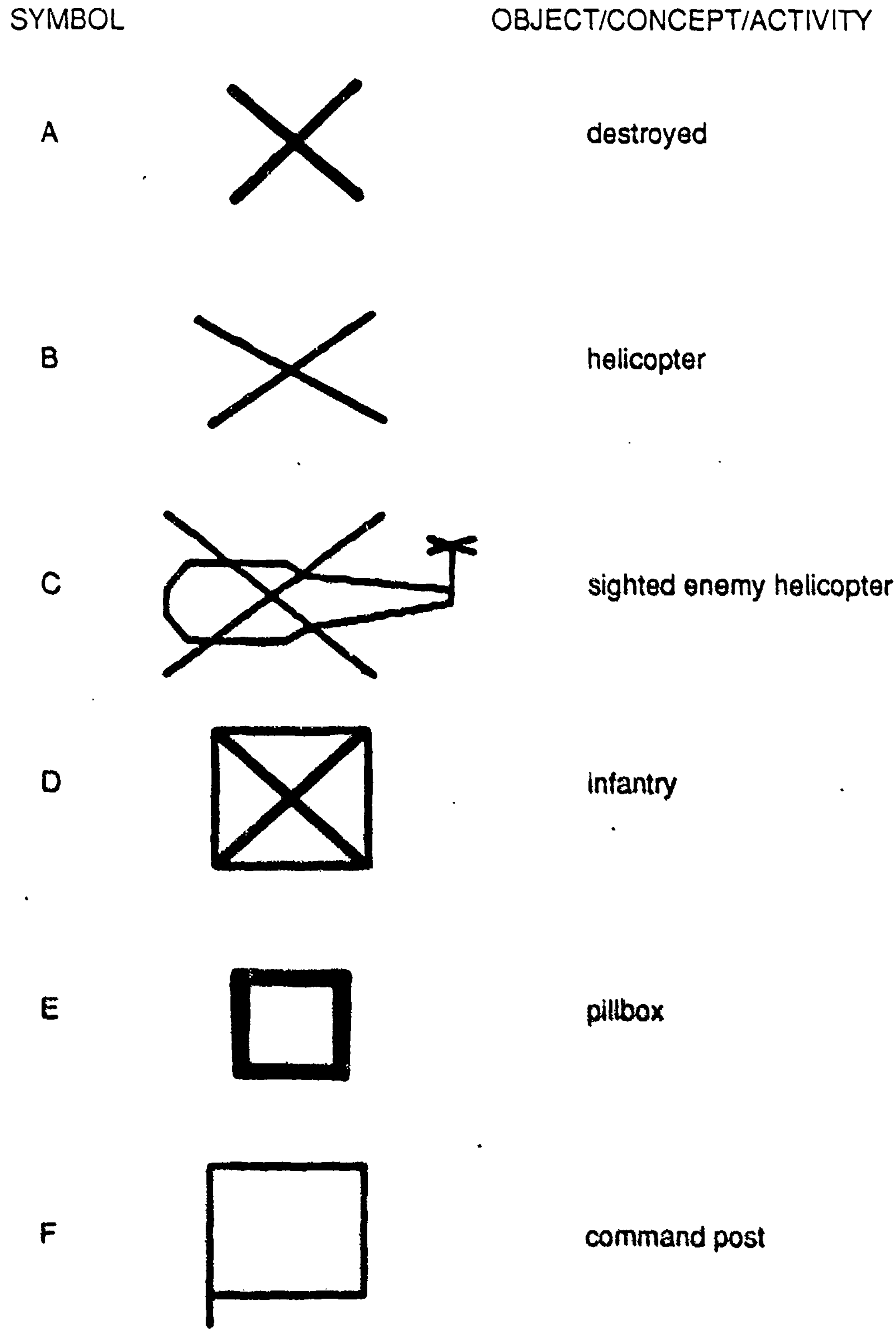


Figure 6. Potentially confusing symbols.

Note. Source references for each symbol may be found in Symbology Sourcebook for Military Applications (pp. 25, 27, 34, 35, 57, 62) by B. G. Knapp, 1986.

In 1979, Parrish, Gates, and Munger (1981) reported that the U.S. Army had more than 60 computer-based information systems in various stages of development. Because system users and operators transfer from one system to another during their careers, and because users of one system frequently must interact with the users of another system, Parrish et al. (1981, p. 3) stress the importance of designing to assure the "behavioral interoperability" of all systems; that is, the incorporation of design characteristics that enable operators to efficiently transfer to new systems and/or to communicate with operators of other systems. Clearly, a common symbolic language would facilitate such transference and would, therefore, enhance overall system effectiveness. Remington and Williams (1986) have proposed establishing a limited number of specialized symbologies, while Middleton (1977) has indicated that the "ideal situation," although perhaps unattainable, would be to establish a single Department of Defense symbology standard.

Given the apparent lack of progress in symbol standardization, it is perhaps not surprising to find that Carter (1981b, p. 145) reports that

> each of the current Army air defense systems has a unique set of geometric symbology. These sets not only have different symbols, but, when identical shapes are employed in different systems, they represent diametrically opposite and contradictory information.

Note in Figure 3, for example, the use of nearly identical symbols to represent both tanks and antitank weapons (see also Carter, 1981a; Johnston et al., 1983; Knapp, 1986). As Frank (1979) reports, however, the development of a standard symbology alone is insufficient. Numerous unique symbologies have been created for aircraft head-up displays (HUDs) even though a human factors engineering specification dealing with HUDs (MIL-D-81641[AS](Department of the Navy, 1972)) has been in existence for some time (see also Green, 1977). Symbology-relevant standards and guidelines reviewed as part of the present effort are listed in Appendix A.

Hemingway et al. (1979, p. 1-9) reported a "general agreement" that new symbology was required for computer-generated graphic tactical displays, but found no consensus regarding what kind of set was required. Key issues to be considered in deciding whether to adopt a single standard versus multiple, specialized symbologies have been set forth by Middleton (1977). These include requirements for

- facilitation of a "graphics exchange" between operational systems,
- efficient operator knowledge transfer because of symbol set familiarity,

- interoperability with systems of other services and allied forces, and

- system flexibility to accept new symbols.

It is still uncertain that an across-the-board standard symbology is possible or even desirable (cf. Geiselman et al., 1986 and Middleton, 1977). It is clear, however, that any such set(s) must be designed for worst-case scenarios with respect to personnel, operational, and hardware characteristics.

The Approach to an Ideal Symbology

More than 25 years ago, Howell and Fuchs (1961) recommended that an "Operational Situation Analysis" be conducted as a precursor to graphic symbol development. Such an analysis is comprised of three components:

1. a personnel analysis including an inventory of the general intelligence level, educational background, and occupation of the potential users,

2. an analysis of the operations that are to be performed with the symbols, and

3. an analysis of the viewing conditions and display variables to be encountered.

Not surprisingly, these analysis elements strongly resemble Sidorsky et al. (1979) and their previously detailed criteria for an ideal symbology, as well as the components of a systems analysis. Concern for such issues and use of such techniques are, after all, standard practice in the human factors profession. Unfortunately, however, the typical symbology design process has been characterized as a subjective one (Gagnon, 1980) in which a committee uses their collective intuition to select a set of symbolic representations (Remington & Williams, 1984) for implementation in a specific system. Apparently, either human factors scientists have not participated frequently in symbology research and development during the past quarter century or, for some reason, they have sometimes chosen to do so without their primary design tool--a systems analysis.

This is not to suggest that the development of an effective symbology is a simple process. To the contrary, as depicted in Figure 7, it involves a large number of interconnecting activities. As with most complex tasks, considerable communication and coordination among the activities are required for the "mission" to be successful.

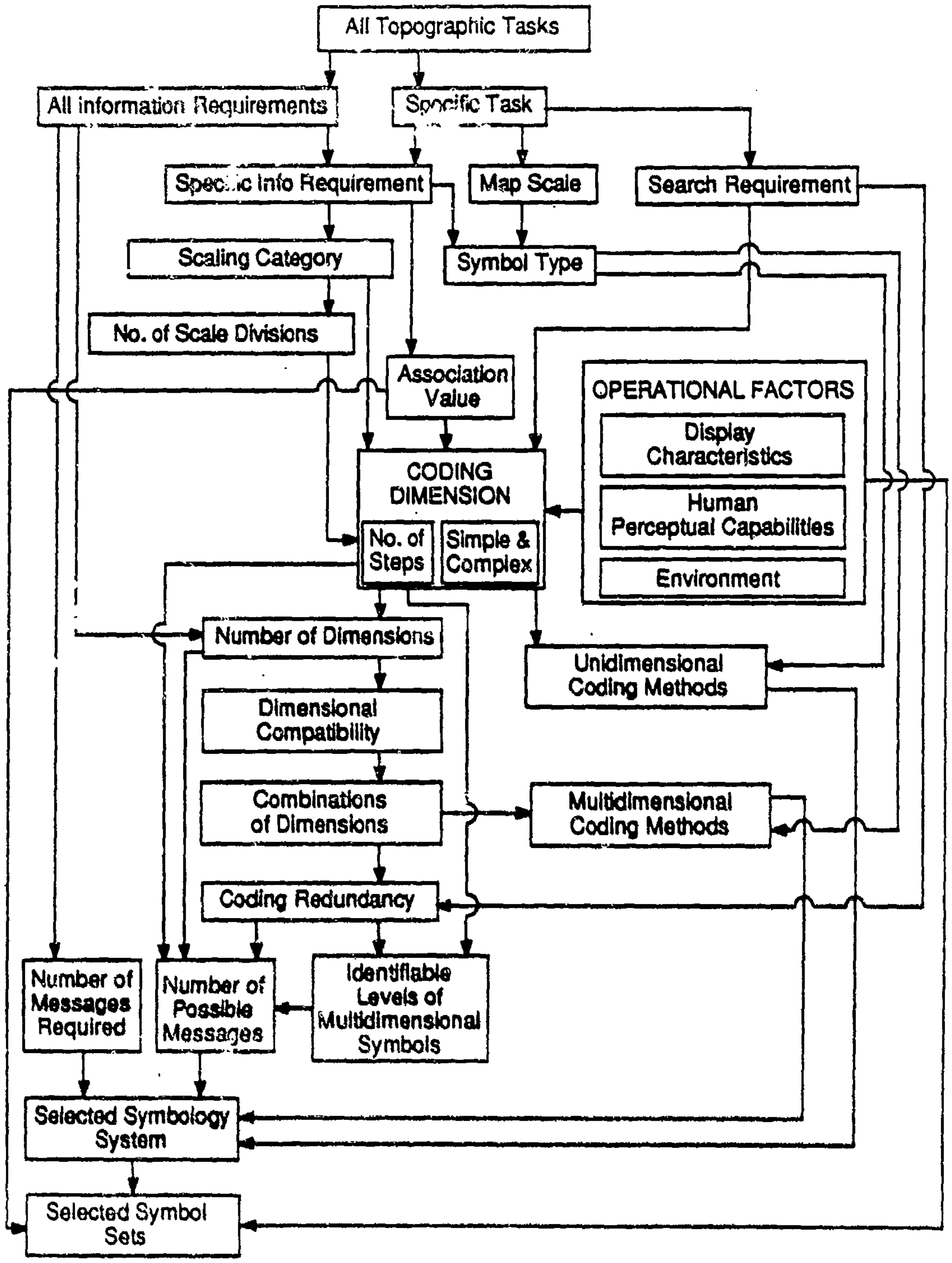


Figure 7. A detailed model of factors critical to effective symbology design.

Adapted from Application of Coding Methods in Development of Symbology for a Computer-Generated Topographic Display Used by Army Aviators by M. C. McCallum and S. P. Rogers, 1982, p. 111.

Current Status

(The next section characterizes the symbology areas being investigated by various, typically military, organizations. Because of the time constraints of this effort, other avenues of symbology research at the organizations cited have undoubtedly been missed, as well as other agencies whose symbology research was not reviewed.)

In 1978, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducted a survey of the Army's activities related to symbology. Symbology-related information such as each group's mission, equipment, issues addressed, and documents produced, was gathered through on-site interviews at nine agencies including ARI and HEL. In summarizing their findings, Sidorsky et al. (1979, p. 12) reported "the survey showed that not only is coordination lacking, there is little consensus as to major problems or in research and development directions." To mitigate this lack of coordination, Sidorsky et al. (1979) recommended the establishment of a working group on tactical symbology within the Army.

Although no assessment of intra-Army symbology research coordination and communication was attempted in the present effort, there was no evidence found of any structure or process having been implemented to alleviate the problems discussed earlier. Currently, however, the Chairman of the Controls and Displays Subgroup of the DoD Human Factors Engineering Technical (formerly Advisory) Group (HFE TG) is in favor of creating a symbology working group within his subgroup (R.N. Armstrong, personal communication, August 1987). Given the existing organizational structure and support provided by the HFE TG, this appears to be the ideal opportunity to establish a formal, DoD-wide conduit for symbology communications.

ARI, for a number of years, sponsored a well-structured symbology research and development program. This included contract, in-house, and joint efforts (see e.g., Bersh et al., 1978; Ciccone et al., 1979; Knapp, 1984), as well as research performed at or through ARI Headquarters, at Ft. Bliss, Texas, or at Ft. Hood, Texas (see e.g., Hemingway et al., 1979; Knapp, 1986; Sarli & Carter, 1982). While a substantial amount of symbology research was conducted during the life of this program (see Knapp, 1986; Kubala, 1979; Landee & Geiselman, 1984 for reviews), the development of an automated tactical symbology (TACSYM) database (Johnston et al., 1983; Peck & Johnston, 1984) and the publication of the Symbology Sourcebook for Military Applications (Knapp, 1986) are among the most significant outcomes (these resources are described further in Appendix B). Although ARI-sponsored symbology research appears to have been discontinued in the mid-1980s, leaving TACSYM development incomplete, Sidorsky, Parrish, Gates, and Munger (1984) did publish a guidelines document for battlefield displays that contained some symbology design-relevant information.

In addition to those organizations surveyed by Sidorsky et al. (1979), other U.S. Army agencies supporting symbology-related activities include the following:

- Guidance and Control Directorate, U.S. Army Missile Command, Redstone Arsenal, Alabama. Work includes the study of display symbology for forward area air defense - command, control, and intelligence (see e.g., McLaughlin & Barclay, 1987)

- U.S. Army Avionics Research and Development Activity, Ft. Monmouth, New Jersey. Work includes computer-generated display symbology for tactical situations (see e.g., Jarosz & Rogers, 1982; Shupe & Bernabe, 1986)

- U.S. Army European Research Office, London, England. Work includes studies of cartographic symbology and lettering (see e.g., Yoeli & Loon, 1972)

- U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland. Although at the time of the ARI survey HEL had "no direct assignment in tactical symbology," (Sidorsky et al., 1979, p. B-39) the present effort as well as proposed research on information-encoding techniques on symbology perceptibility (J. K. Schmidt, personal communication, August 1987) indicates an ongoing symbology interest within the Aviation and Air Defense Division

There is little U.S. Navy representation in either TACSYM (Johnston et al., 1983) or the Symbology Sourcebook for Military Applications (Knapp, 1986) beyond what is related to U.S. Marine Corps symbologies (see also, Perceptronics, 1981). A Navy tactical display system symbology has been developed, however, (see e.g., Bruck & Hill, 1982) and the Naval Ocean Systems Center has conducted research on perspective 3-D displays for command and control applications (Louie, 1984). Additionally, the Naval Air Development Center has investigated symbologies for helmet-mounted displays for helicopter pilots (Donley & Dukes, 1983).

Although not specifically related to visual tactical symbology, the Naval Training Analysis and Evaluation Group has developed training techniques and strategies to enhance acquisition and recall of symbolic information (see e.g., Ainsworth, 1979; Braby, Hamel, & Smode, 1982). Finally, while there appears to be an ongoing interest in symbology issues at the Naval Postgraduate School, much of this research is in the form of master's theses by non-U.S. Navy students (see e.g., Bruck & Hill, 1982; Hawrylak & Miller, 1985; Kafurke, 1981).

As might be expected, U.S. Air Force interest in symbologies has centered around aircraft display technologies including HUDs (see e.g., Loverling & Andes, 1984), different CRT types (see e.g., Kopala et al., 1983), and LED displays (see e.g., Hawkins et al., 1984). In acknowledging operational demands, the Air Force has also examined the compatibility of HUD symbology with the use of night vision goggles (Walker, 1985).

Although symbol set development has typically occurred on a system-by-system basis (see e.g., Newman & Foxworth [1984] for a HUD-related review), Gagnon (1980) has developed an algorithm called the predictor of visual performance (PREVIP) with which to evaluate candidate visual symbol sets. "The intent of PREVIP is to aid in the development of a specification (or military standard) for optimal symbol sets" (Gagnon, 1980, p. 3). Also said to be formed system by system (if at all) are groups such as the Symbology Standardization Committee of human factors personnel that developed a "preferred tactical symbology" for implementation with the Joint Tactical Information Distribution System (JTIDS) (see Pearson et al., 1979).

Finally, the National Aeronautics and Space Administration has also directed research towards aircraft display symbologies. Remington and Williams (1984, 1986), for example, have studied visual search times for helicopter CRT display symbols and Abbott et al. (1980) conducted an in-flight investigation of cockpit-displayed traffic information symbols.

CONCLUSIONS

Three themes emerged from the present effort. First, across all agencies, operations, and systems, there is a recognized need for improved symbologies in order to maintain or enhance efficiency under increasingly difficult operational conditions. Second, there is a general, if ill-defined, call for some degree of symbology standardization. Third, one or more aspects of a traditional systems approach to design are frequently considered crucial elements of the operational system for which a symbol set is being developed.

The need to view symbology from a systems perspective is evidenced by the numerous voids in the current body of symbology knowledge. Although many inter- and intraindividual differences are known to affect human performance on a variety of tasks, apparently little assessment has been made of their impact on symbolic information acquisition and retention. Further, while many operational considerations (e.g., use of night vision goggles) have influenced symbology design, other potentially critical influences such as combat stress apparently have not. Finally, perhaps as a result of the rate at which new display technologies are being developed, only CRT and HUD technologies have been subject to repeated evaluation of their symbol presentation effectiveness.

Two actions appear essential in charting an efficient and meaningful course for symbology research. First, an assessment must be made of the current status of all symbology research programs regarding mission, approaches, problems, and plans. Second, a mechanism must be created to assure the continued exchange of up-to-date information among members of the symbology research community. The criticality of joint interservice and international military operations requires that these two activities be considered, at least throughout the U.S. Department of Defense.

RECOMMENDATIONS

It is recommended that

- A replication of the survey conducted by Sidorsky et al. (1979) on U.S. Army involvement in symbology development should be required in order to establish a baseline from which to develop meaningful future research. However, given the increasing requirement for interoperability, this effort should be extended to include research organizations throughout DoD, and possibly to such others as the Behavioural Science Division of the Defence and Civil Institute of Environmental Medicine (Canada) and the Royal Aircraft Establishment (Great Britain).

- As part of this proposal, preliminary data on the feasibility and desirability of standardization should be collected.

- The TACSYM automated symbology database should be updated with regard to content and, perhaps, system characteristics. This would provide symbology developers with a standardized tool and would enable meaningful comparisons within the results of the research.

- The opportunity to create a symbology working group at the DoD level within the Controls and Design Subgroup of the Human Factors Engineering Technical Group should be vigorously pursued.

- Considerable research must be directed towards the impact of such personnel influences as user educational level, intelligence, visual system characteristics, primary language, culture, and personality (especially with regard to performance under stressful conditions) on symbology effectiveness.

- The research focus must shift from basic perceptual issues to the higher-level processes required for battlefield decision making.

- Performance-based, subjective, and/or physiological techniques for workload assessment should be incorporated into the development of symbologies designed to enhance complex decision-making performance. In particular, the cognitive load associated with the use of "selective callup systems" should be evaluated.

- The interpretability of laboratory-created symbologies when subjected to operational variables, such as operator sleeplessness, night operations, and combat stress, must be assessed.

- Increased attention must be given to differences in symbol set effectiveness induced by technological variables. This must include consideration of both normal and potentially degraded modes of operation for each display type.

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APPENDIX A

SYMBOLOGY STANDARDS AND GUIDELINES

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APPENDIX B

SELECT ANNOTATED BIBLIOGRAPHY

SELECT ANNOTATED BIBLIOGRAPHY

Ciccone, D. S., Samet, M. G., & Channon, J. B. (1979). A framework for the development of improved tactical symbology (Technical Report 403). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

This report attempts to establish a framework for considering the relevant issues and requirements as well as the design and evaluation principles surrounding improved, user-oriented tactical symbologies. Four categories were used as the basis for queries directed to experienced tacticians: user, task, military operations, and information requirements.

This query-based methodology as well as a three-stage approach to tactical symbology evaluation are detailed.

Geiselman, R. E., Landee-Thompson, B., & Samet, M. G. (1986). A selective callup system for managing tactical information on graphic displays. IEEE Transactions on Systems, Man, and Cybernetics, SMC-16(6), 901-907.

This report describes research directed toward the design, implementation, and demonstration of innovative graphic concepts for supporting tactical decision making. This automated selective overlay system is based on the need to reduce clutter on computer-generated displays adaptively. Users took full advantage of the system's flexibility to reduce display clutter by matching symbol parameters with task demands. The authors believe that it is feasible to develop a set of information processing strategy guidelines that correspond to a variety of tactical situations such as border attacks and withdrawal maneuvers.

Green, G. N. (1977). Head-up display symbology. Farnborough, Hants, UK: Royal Aircraft Establishment. (DTIC No. AD-B030 030).

This report consists of a table and accompanying illustrations to describe the HUD symbology functions in the A-7E, F-5, F-14, F-15, F-111A, CL-84, AV-8A, Harrier, Sea Harrier, Jaguar, MRCA (IDS and ADV), and F-16 aircraft as well as the AN/AVQ-7(V) HUD set. Comparison data are presented from MIL-D-81641(AS) (Military Specification for General Head-up Displays) and MIL-STD-884B (Military Standard for Electronically or Optically Generated Displays for Aircraft Control and Combat).

Johnston, S. C., Peck, P., & Landee, B. M. (1983). Tactical symbology catalog (Research Product 83-6). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

This is a hard-copy version of the automated tactical symbology database, and its pages have been directly generated from TACSYM. Over 1,000 symbols representing 17 symbol sets are categorized and depicted.

Accession routes are by symbol source (e.g., FM 21-30), symbol category (e.g., weapon, aviation, etc.), and specific concept (helicopter, radar, etc.). Additionally, symbols marked as "highly discriminable" may be requested and symbol construction may be accomplished through selection of symbol "primitives."

Knapp, B. G. (1986). Symbology sourcebook for military applications (Research Note 86-74). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Reproduces the TACSYM database (see Johnston, Peck, & Landee, 1983) and a large number of other symbology sets from such applications as air defense, radar, TACFIRE, and commercial war games, in addition to a number of experimental symbologies. A brief review of the ARI program is given and symbology design procedures and guidelines are discussed.

McCallum, M. C., & Rogers, S. P. (1982). Application of coding methods in development of symbology for a computer-generated topographic display used by Army aviators (Report No. 81-0089-2). Fort Monmouth, NJ: U.S. Army Avionics Research and Development Activity.

This document details and evaluates symbol-coding techniques such as shape, alphanumeric, size, numerosity, inclination, brightness, color, flash rate, stereo depth, and apparent movement used on topographic and tactical displays. The types and the appropriate use of redundant coding techniques are discussed, and a model of critical symbology design factors is presented.

Peck, P., & Johnston, S. (1984). Automated tactical symbology system: System design specifications (Research Product 84-06). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

This document presents TACSYM system specifications.

Sidorsky, R. C., Gellman, L. H., & Moses, F. L. (1979). Survey of current developments in tactical symbology: Status and critical issues (Working Paper HF 79-03). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

This paper presents the results of a survey of nine U.S. Army agencies that have researched symbology issues. Data regarding each group's symbology mission, their personnel, the problems studied, the documents produced, and the planned research directions are presented.

Research issues are discussed and a symbology classification scheme as well as a proposal for a working group on tactical symbology are set forth.